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DISCUSSION OF FLOATING TUNNEL FOR LONG WATER CROSSINGS

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Charles E. Andrew

STRUCTURAL DIVISION

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DISCUSSION

ROBERT S. MAYO,[4] M. ASCE.—From an engineering standpoint, the idea presented in this paper is feasible; but, from an economic standpoint, it appears questionable that the future traffic would ever repay the great investment involved.

Several criticisms suggest themselves: (1) The ventilation of the 3-mile vehicular tunnel would be quite a problem and would be a continuing expense; (2) the external inspection of the tube and of the anchor cables would be expensive and, should repairs ever become necessary, the cost would be prohibitive; and (3) the most serious, should a leak ever develop in this tube, as the result of accident or of sabotage, the entire structure, 3 miles long, would be sunk beyond recovery in water from 600 ft to 800 ft deep and any motorists in the tube at that time would be drowned like rats in a trap.

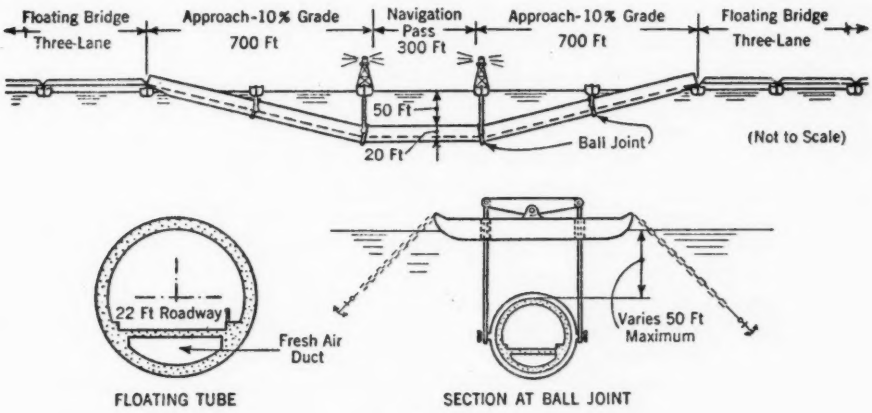

FIG. 5

Mr. Andrew mentions his investigation of a floating bridge. Why not combine the ideas of the floating tube and the floating bridge as illustrated by Fig. 5? This crossing would have a total length of approximately 2.75 miles and it could be made up with large boatlike pontons, with a three-lane (or four-lane) bridge of economic span length. There would be no particular problem in the inspection and maintenance of such a floating bridge. Furthermore, the anchor and the anchor cables could be removed periodically for inspection.

For the navigation pass, the writer suggests the floating tube. The total length, including the approaches would be about one third of a mile. This tube would be comprised of five sections, each about 350 ft long, suspended from pontons. Each section is connected to the next section by a ball-and-socket

NOTE.—This paper by Charles E. Andrew was published in March, 1950. The numbering of footnotes and illustrations in this Separate is a continuation of the consecutive numbering used in the original paper.

[4] Civ. Engr., Lancaster, Pa.

joint so that there would be no internal strains due to twisting. These ball-and-socket joints would have a secondary advantage. They would allow the tube to be raised almost to the surface for inspection; and, should repairs ever be necessary, the entire floating tube could be taken ashore to a dry dock, service being maintained meanwhile by a floating drawspan.

Mr. Andrew may object to funneling this traffic through one two-lane tube for the water crossing. The Pennsylvania Turnpike probably now carries more traffic than this proposed crossing will ever handle in its foreseeable life. The Pennsylvania Turnpike is four lanes throughout, except when passing through the seven tunnels, where it is reduced to two lanes. These two-lane tunnels handle all the traffic (about 4,000,000 vehicles per year) without noticeable delay.

The author is to be congratulated on his bold and novel approach to a very difficult problem.

HOMER M. HADLEY,[5] M. ASCE.—The proposal for crossing Puget Sound at Seattle (Wash.) by a floating tunnel is not to be criticized so much in terms of abstract thinking and conception as it is for the practical aspects of execution and financing. Assuredly a floating tunnel, anchored and restrained from vertical or horizontal movement and possessed of buoyancy in excess of all possible downward loads to come upon it, is a warranted and justifiable idea. However, if its construction involves such grave risks and hazards that contractors would hesitate to bid on the work, and bondsmen would hesitate to write surety bonds, and if neither would do so except at almost preposterously high figures; if continuous risks and hazards made bond buyers reluctant or unwilling to buy bonds, or made insurance men unwilling to write insurance on the structure—then, regardless of abstract merit, the project is impractical and, as such, may be dismissed from further consideration. There is little point in talking about a project on which bids, surety bonds, and sale of revenue bonds and insurance are not obtainable except at what would appear to be fantastic cost. This, to the writer, appears to be the case here.

Anyone familiar with Puget Sound geography, or examining United States Coast and Geodetic Survey chart No. 6446, knows (or will know) that there are three and only three narrow places in Puget Sound in the vicinity of Seattle. These are the sites which Mr. Andrew—and indeed almost anyone else—selects as possible sites for a crossing. It is unfortunate that Mr. Andrew's maps of Figs. 1 and 2 include only the westerly part of Seattle. They do not show the full city and its central business district, they do not show the full size of the waterway to the east of Vashon Island, and they do not designate the City of Bremerton, Wash., the principal center of population and industry on the west side of Pudget Sound. If the business center of Seattle were shown and the City of Bremerton were designated, it would be apparent to everyone looking at these maps that the Alki Point-Restoration Point site which Mr. Andrew designates as site A lies closest to a straight line between the centers of the two cities. Both of his other two routes depart quite widely, and by a considerable number of miles, from this desirable straight line. Moreover site A is the only location

[5] Cons. Engr., Seattle, Wash.

in solid rock anywhere along the entire length of Puget Sound, a fact of no mean advantage whatever is built there.

The proposal with respect to route B—to close off the main channel to the east of Vashon Island, now used by practically all large ships going to Tacoma, Wash., with a barrier such as a pontoon bridge of the Lake Washington type "but of deeper draft and heavier wall construction," and having only a 400-ft movable span—certainly deserves the characterizations Mr. Andrew bestows on his submerged tunnel (under the headings, "Results of Studies: The Tube" and "Conclusion"): "* * * rather bold * * *" and "* * * rather daring and unusual." To close the main, wide marine approach to Tacoma and compel shipping to use Colvos Passage on the west side of Vashon Island, one third to one quarter as wide, is certainly a novel thought.

It is true that Colvos Passage is a vastly wider and more spacious waterway than many a river port in the world enjoys. Nevertheless the fact remains that Tacoma now possesses both of these free and unobstructed approaches, that ocean shipping now uses the east passage, that the United States Navy base at Tacoma now possesses both approaches, that in foggy weather (of which there is considerable) a wide channel is much to be preferred to a narrow one, and, lastly, that approval for such a closure must be obtained from the United States War Department before it can be consummated. Bare sketches showing no more than the general features of the proposed construction, and its horizontal and vertical clearances, and requiring the expenditure of only a few dollars to produce, would be sufficient to accompany an application for War Department approval. A public hearing would follow, presently a decision would be forthcoming, and the question would be resolved. Since in all probability the decision would be adverse to the pontoon construction, it may be stated that all three of Mr. Andrew's sites involve the use of floating tunnels.

What is wrong with the floating tunnel idea? It is not original with Mr. Andrew. A Swedish patent was issued on the idea in 1890. In the 1939 report on the proposed Mackinac Straits bridge (Michigan) it is stated that a submerged tunnel was proposed for that site in 1920. Undoubtedly it has been considered at various times in the past, for sites much more favorable than that across Puget Sound at Seattle. Why has not one floating tunnel, short or long, that relies on "restrained buoyancy" for stability ever been built anywhere in the world? Undoubtedly this is because of the dangers and hazards involved in constructing a floating tunnel and because of the dangers and hazards inherent in it ever afterward even if it is built successfully.

What is the essential nature of a submerged tunnel of this type? It is a tunnel, a continuous, unbroken, uninterrupted hole from one end to the other surrounded on all sides by water, having no fixed and unyielding supports anywhere along its length and, of course, from its very use and service, devoid of transverse watertight bulkheads. At all times and everywhere along its length it is possessed of the urge to break loose from the anchor cables that hold it down and to lunge upward to the surface and to the atmosphere. Well, what can happen to it? It is anchored down and nothing can happen to it. So likewise, nothing could happen to the Tacoma Narrows Bridge before its spectacular failure. This is certain, however: If anything does happen to rup-

ture the shell of the floating tunnel—if anchor lines slip or fail, if anchors resembling the sole fish settle into the "soft on the surface" bottom of Puget Sound under their pressure of "approximately 500 lb per sq ft," if from any cause whatever water ever breaks through into the interior and floods the tunnel—then all buoyancy is lost and inevitably there follows complete, utter, 100% catastrophic loss of everything from shore to shore! Ruin is complete and overwhelming!

Who wants to write insurance on such a structure? What contractor wants to assemble, connect, and join the sections for such a tunnel? They are 400 ft long, 30 ft high; weigh thousands of tons out of water; and lose none of their mass, inertia, or size submerged. There is nothing to set them down upon and they must be brought into true alinement, both horizontal and vertical, for connection while tidal currents whose "maximum velocity does not exceed 2 miles per hr" press upon them and tend to throw them out of line. Then, once joined, all bulkheads except the last are removed and taken to shore through the completed portion of the tunnel which now possesses all the hazards plus that of a single removeable end bulkhead which the completed tunnel would have.

Who wants to enter into a binding and irrevocable contract to construct such a tunnel? Who wants to write the surety bond that, in the event the original contractor fails to fulfil the contract, his company will fulfil it? In Lewis Carroll's poem, "The Walrus and the Carpenter," the walrus invited the oysters to come and walk with them along the briny beach. Thereat

> "The eldest Oyster looked at him,
> But not a word he said.
> The eldest Oyster winked his eye
> And shook his heavy head—
> Meaning to say he did not choose
> To leave the Oyster-bed."

It is highly probable that contractors, bondsmen, and insurance men will react as did the eldest oyster. If they feel any impulse to do otherwise they had better get the poem and read what happened to the young oysters who did accept the invitation.

In this paper Mr. Andrew refers to the remarkable financial success of the Lake Washington Floating Bridge and the great developments that have occurred on Mercer Island and the east shore of Lake Washington. Reference can likewise be made to the success of the Transbay Bridge at San Francisco, Calif. What do these facts prove? Undoubtedly similar developments would follow the construction of a crossing of Puget Sound at Seattle, but the degree of similarity is conditioned by and dependent on the degree of similarity that the conditions on the west side of the Sound bear to those on Mercer Island and the east shore of Lake Washington, or to those on the east side of San Francisco Bay. Similarity of development likewise depends on the toll to be charged for passage. No toll as low as 25¢, reduced by commutation rates, will be charged for crossing Puget Sound with a $50,000,000 or $60,000,000 or $125,000,000 structure. This is simply because there is not the volume of traffic there now, or to be foreseen in the future, to justify such moderate transbay or floating bridge rates.

The sole industrial city in the entire area west of Puget Sound and east of Hood Canal is Bremerton (see Fig. 6) and its sole great industry is the naval shipyard there. This is the largest ship repair base north of San Francisco. During the World War II Bremerton grew tremendously, attained a population of 75,000. By 1950 it had shrunk to somewhat less than 30,000. Not until the war years was continuous rail connection established between Bremerton and the remainder of the state; and this connection extends southwesterly for 55 miles before it can swing back in an easterly direction toward the Puget Sound cities and the railroads across the Cascade Mountains. No continuous

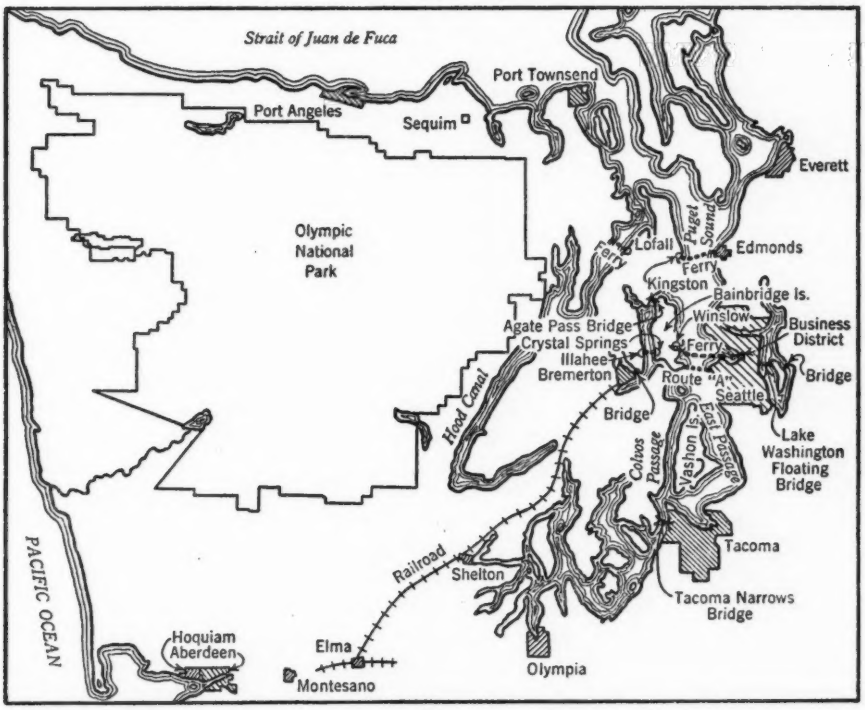

FIG. 6.—MAP SHOWING ENTIRE WESTERN AREA TO BE SERVED BY TRANS-SOUND CROSSING AT SEATTLE, WASH.

rail line extends northward either to the east or to the west of the great block of Olympic Mountains, which occupy most of the area between Hood Canal and the Pacific Ocean. The Chicago, Milwaukee, St. Paul and Pacific Railway has a road along the strip of benchland to the north of the Olympics and south of the Straits of Juan de Fuca, with car ferry conncetion to Seattle. Here in this north Olympic zone of Washington are three small cities: Port Angeles (about 12,000 population) with lumber mills and paper mills; Port Townsend (about 5,500 population) with an army post and a paper mill; Sequim (population about 1,000) with a shopping center for the surrounding agricultural and dairy district. By air Port Angeles is 60 miles distant from Seattle.

Most of the low lying areas between Puget Sound and the Pacific Ocean are covered with glacial deposits of clays, sands, and gravels. There are rich farms in certain areas, not so rich in others. There is magnificent scenery everywhere. There are hundreds of miles of beautiful waterfronts along Puget Sound, Hood Canal, and all the bays and inlets and passages that cut and indent the area. There are the ocean shores and those of the Straits of Juan de Fuca. Some day when the Columbia River is bridged at Astoria, Ore., and a few miles of road are built through easy country, a main north-south Pacific highway (coming up from San Francisco through the redwoods and along the wondrously beautiful Oregon Coast) can be brought into Bremerton and will contribute traffic to a trans-Sound to Seattle crossing.

The fact is, however, if anything is to be accomplished, both routes and all structures must be carefully studied and reviewed. Two examples of this fact are to be seen in Fig. 2. Since Bremerton is the main center of population to the west of Puget Sound; since Alki Point-Restoration Point route is the most direct route from the center of Seattle to Bremerton and for connection with all other points and areas of the entire Olympic Peninsula except Vashon Island and the territory immediately south of Rich Passage; and since neither of the other two routes offer any advantages to compensate for their considerably greater mileage—it may be accepted by everyone that the Alki Point route is the best one and is the one on which attention should be focussed and concentrated. Again, from Fig. 2, it is seen that Mr. Andrew's suggested highway swings northwesterly from Restoration Point almost halfway up Bainbridge Island to cross to the west mainland on a "4-lane pontoon bridge" and then completing the big loop by swinging back to Bremerton.

One would infer that there existed some strong and compelling reason for such a location. Actually there is none. About 2 or $2\frac{1}{2}$ miles south of the pontoon bridge, the map shows a small creek emptying into the channel on the west side. Here is the shallowest water anywhere along the west side of Bainbridge Island, with 97 ft of extreme depth, most of it from 60 ft to 70 ft and a quarter mile on the west side not deeper than 18 ft. Since the water deepens both to the north and to the south of this line (which lies squarely athwart the north-south path of the glacier that once plowed through this area), it is a fair assumption that this submerged ridge is of firm, hard material.

At this Crystal Springs-Illahee location a structure on fixed unyielding foundations is possible. Why introduce 4 or 5 miles of useless distance between Seattle and Bremerton in order to build a pontoon bridge with a 500-ft required opening in it in tidal waters having a range of 17.5 ft? Fig. 2 is in error at the Illahee location in not showing the little creek forking and providing a southward extending branch up which the road could ascend to the top of the bench-land on about a 5% grade.

Despite his negative attitude toward Mr. Andrew's proposals, the writer is sympathetic to the trans-Sound crossing project and would like to see it consummated. He believes it can be done, at not too great a cost, by construction free from great hazard, on which contractors would have no hesitancy in bidding; but it can only be effected by holding costs to a minimum and it will not be done with floating tunnels, regardless of Mr. Andrew's judgment that a floating tunnel is the "only possible method" of crossing Puget Sound.

CHARLES E. ANDREW,[6] M. ASCE.—Answering Mr. Mayo's criticism, the writer believes that an expenditure as high as $75,000,000 is justifiable from an economic point of view. The total income from ferries in past years has been as high as $7,000,000, with a conservative average income of $5,500,000; 72% this sum is derived from the ferries that would be replaced by a sound crossing, or approximately $4,000,000. Induced traffic via the bridge would increase total traffic at least 100% and would result in an average income of about $5,400,000 at tolls approximately 35% lower than the 1948 tolls.

An income of $5,400,000 in the first year of operation will take care of debt service and will retire a bond issue of $90,000,000 in 20 years or less; also, of course, it will retire a $60,000,000 to $65,000,000 bond issue at a toll rate of 50% or more below 1948 rates.

It is of interest to note that the population of the State of Washington has increased almost 40% in the decade, 1940–1950; the ferry traffic at The Narrows has increased at the rate of 5.9% compounded since 1942; and automobile registration has increased at the rate of 8% a year in the 3 years since 1947.

Ventilation is a problem, of course, but has been solved successfully in other tubes. Its cost is taken care of in operating expense.

Metals which are practically everlasting in salt water are available for vertical anchor lines. Lateral anchors can be designed for renewal when necessary. External inspection by divers is quite practical in depths of 90 ft, which is the approximate depth of the bottom of the tubes. Deterioration of the heavy walls (which are 3 ft to 3.5 ft with steel imbedded 6 in.) should not be more rapid than that of walls of similar bottom tubes already constructed. Likewise, the danger of leaks is no greater than in existing tubes subject to greater hydrostatic head.

As to Mr. Mayo's suggestion for a tube in connection with a floating structure, a similar layout is under consideration, except for the use of twin tubes with longer opening and less approach grades. A single tube is insufficient to handle potential traffic. The tube suggested, however, does present practically the same hazards as those mentioned by Mr. Mayo. He indicated no method of ventilation, and ventilation would be necessary.

In answering Mr. Hadley's comments, it is necessary first to familiarize the reader with the conditions under which the investigation of bridging Puget Sound was made.

The writer was requested by the Director of Highways to make the investigation for the purpose of ascertaining whether or not it would be possible and feasible to cross Puget Sound by means of an uninterrupted highway, and in so doing, eliminate the present ferry system. The prime object of such an undertaking is to extend the present transcontinental highway (which now ends in Seattle) to the Pacific Ocean. Then it will serve not only the immediate territory on the west shore but also the entire vast area west of the sound, extending to the ocean. It will thus develop an area that is isolated by the handicap of ferry transportation.

It makes no practical difference whether the most northerly, central, or southerly location is selected. In constructing major highways across mountain ranges, the planner must use those passes which nature has provided

[6] Chf. Cons. Engr., Washington Toll Bridge Authority, Tacoma, Wash.

whether they be north or south or east or west of the most direct line. In this study three possible sites are available and are being considered. In the writer's opinion, the population immediately adjacent to the west shore is not the whole picture by any means. However, if it actually were, the distance between the business center of Seattle and Bremerton by route A is only 1½ miles less than by route B, whereas the distance between the center of population of Seattle and Bremerton is considerably less by route C than by either routes A or B. Thus, there is little choice as far as distances are concerned. It then becomes a question of cost of transportation (tolls). In this respect route B has the advantage because of its lesser cost.

At the time this paper was written, the writer had indicated no preference between locations. On further study he has given preference to site B because it incorporates proved construction and less cost, while at the same time it serves more traffic. He does not condemn the use of floating tubes, however, if they should become necessary to solve the problem because of any possibility that they are dangerous, or because they cannot be financed, or because contractors will not undertake their construction. That is one man's opinion. Why was it that engineers experienced in major bridge construction condemned the Lake Washington Bridge and predicted dire consequences; yet it was successfully built and paid for? Why was it that many prominent men and engineers insisted that it was dangerous and impossible to build the San Francisco-Oakland Bay Bridge, in California, because of foundation depths far in excess of any built prior to that date? Why is a floating tube subject to hydrostatic pressures approximating 85 ft any more dangerous than the many bottom tubes now in existence, which are subject to greater heads and are held down by rock or earth instead of anchors? They require the same method of connection, the same alinement, and the same hazard of assembly.

As to the question of navigation, if site B is adopted, the writer contends that a floating bridge across the east channel will result in very little inconvenience to shipping to Tacoma or Olympia, Wash. Colvos Passage affords the shortest and most direct route to both cities. It is a mile wide and is 300 ft deep throughout its length, with maximum tidal velocities of less than 2 miles per hr. Any ship wishing to use the east channel may do so. It is a moot question as to why land transportation should always be subservient to water transportation even when the latter is slightly inconvenienced. Both are equally important to the development of the United States.

Mr. Hadley proposes a crossing of Port Orchard Channel at Illahee Crystal Springs instead of the one shown on route A. The length of his proposed crossing is nearly twice as long as the one proposed, and the United States Navy has refused to permit any bridge to be built south of the site proposed on route A. Mr. Hadley states that he is sympathetic to a sound crossing and infers that he has a cheap method of doing so. The writer is not informed as to his proposal. It is not a fact that the writer has said that the only method of crossing Puget Sound is by floating tunnels. The writer has said that, in his opinion, the floating tunnel is the only method of crossing by highway on routes A and C. There remains, of course, the continuance of consolidated ferries; but ferry transportation will never fully develop the vast area to the west of the sound and will always be more expensive in the long run.

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